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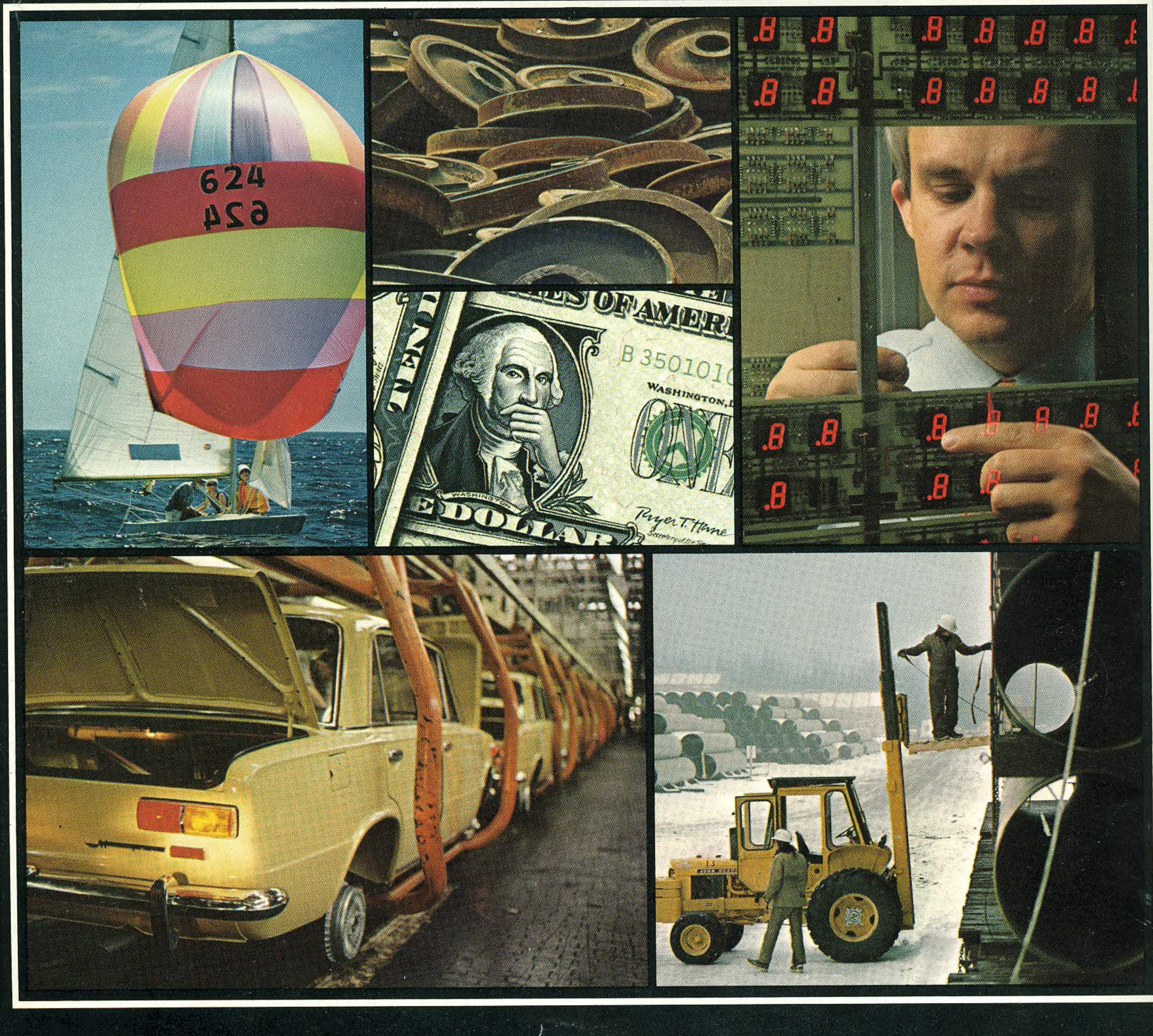
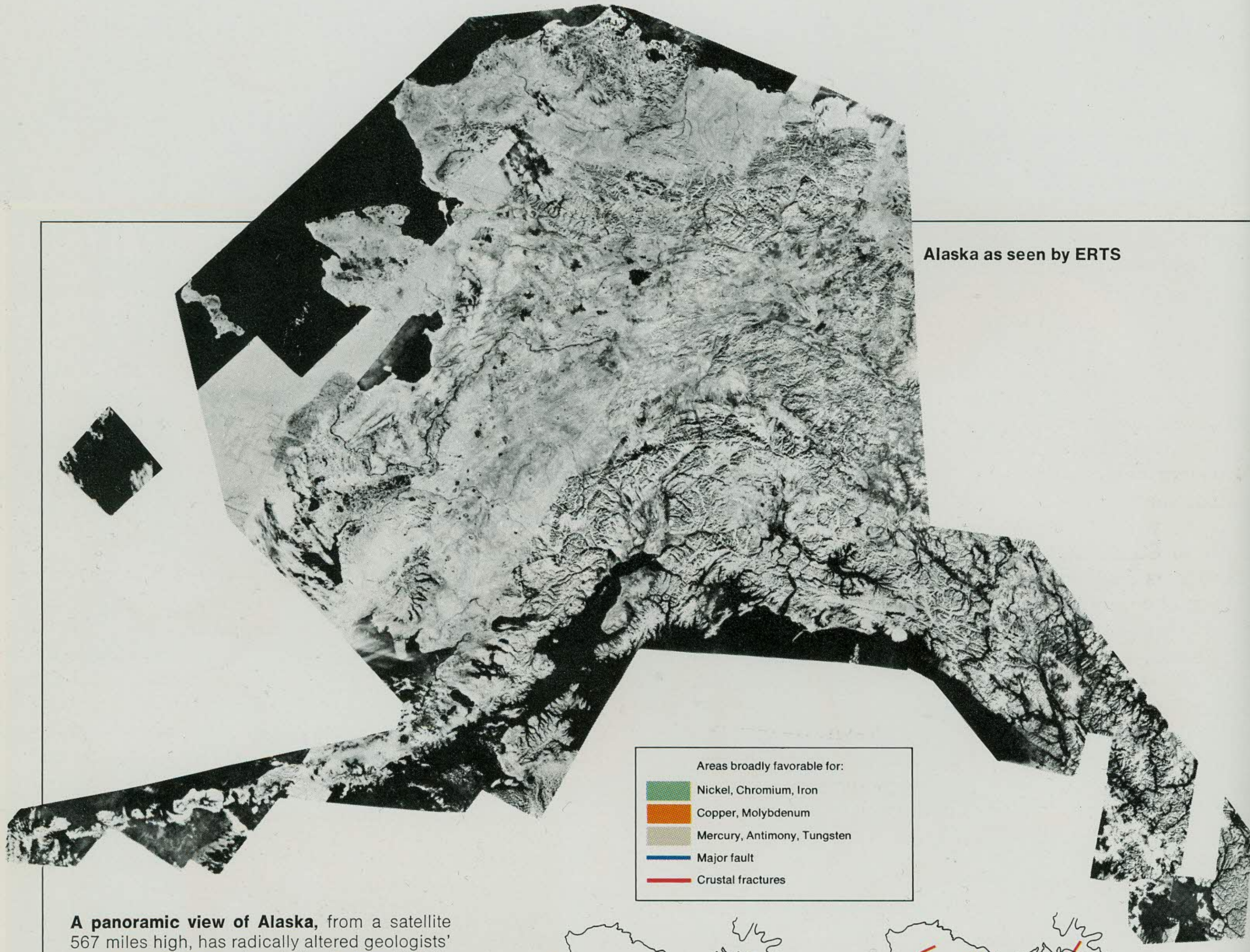
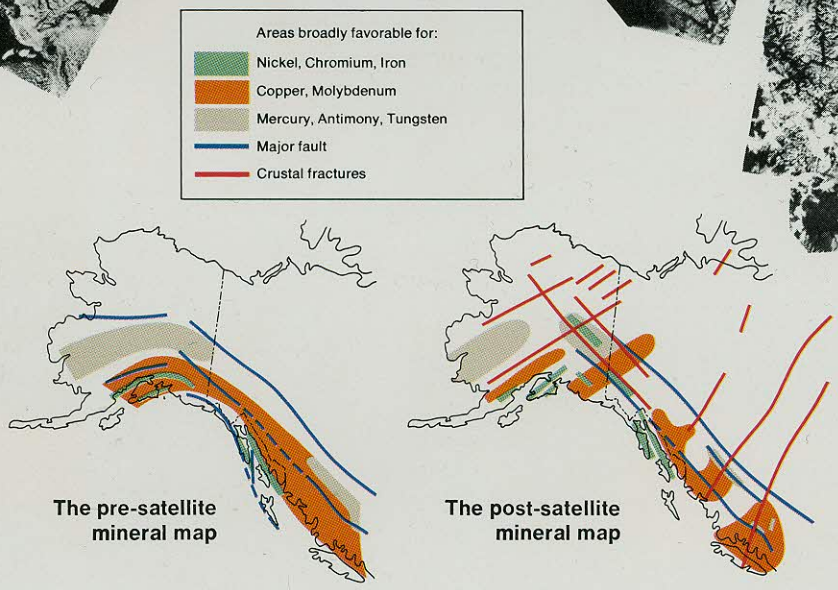




Alaska as seen by ERTS



The pre-satellite mineral map

The post-satellite mineral map

A panoramic view of Alaska, from a satellite 567 miles high, has radically altered geologists' concepts of where minerals lie. Before NASA's Earth Resources Technology Satellite was launched, geologists thought the metal- and mineral-bearing areas of Alaska and northwest Canada stretched in a continuous line along the Pacific Coast. But when he analyzed the satellite images, Ernest H. Lathram of the U.S. Geologic Survey located previously unknown faults. Knowing that minerals and metals are forced up from the earth's interior along such fractures, he revised the resources map. Two new finds of copper and molybdenum have since supported Lathram's hypothesis.

ERTS Puts the Whole Earth Under a Microscope

NASA's first resources satellite is opening great vistas in mineral prospecting, agriculture, map making, and other fields.

by Gene Bylinsky

One of the strangest and most forbidding places on earth is a huge salt desert called the Great Kavir, which lies between the populous northern and southern parts of Iran. It is covered with treacherous salt swamps and deep depressions hidden by a brittle salt crust that can collapse beneath the footfall of a man. Underground water unpredictably swells the spongy land, setting off streams of brine. In the past, only occasional camel caravans ventured into this desolate scene, and some are said to have vanished without trace. For centuries, prudent travelers have chosen to go 500 miles out of their way rather than cross the dangerous desert.

Shortly after rocketing from Vandenberg Air Force Base in California two and a half years ago, the Earth Resources Technology Satellite began crossing the Great Kavir once every eighteen days, taking pictures of the land below. At the U.S. Geological Survey's headquarters in Reston, Virginia, Daniel Krinsley, a geologist, studied the images. He was able for the first time to determine the extent of the hazardous areas and to trace a route for an all-weather road through the Great Kavir. He then flew to Iran and explored the salt desert by helicopter to confirm the route. Thanks to the satellite's pictures and Krinsley's work, the Iranians are studying the possibility of spanning the great salt desert with a six-lane highway.

"Now we see the elephant"

Because of the desert's vast size, discovering its secrets by conventional aerial photography would have been prohibitively time-consuming and expensive. The achievement typifies the remarkable contributions of the Earth Resources Technology Satellite, better known as ERTS-1. Launched by NASA to determine just how effectively the earth's resources could be surveyed from space, it makes great sweeps from pole to pole, viewing every section of the earth except small areas near the poles themselves. Before it was launched, U.S. scientists thought the satellite would provide experimental data useful mainly to federal agencies, such as the Interior and Agriculture departments. But the satellite's sterling performance and the wide applications that have been found for its data have surprised and delighted its designers.

Research associate: Peter Schuyten

ERTS is opening up great new vistas in map making, geology, and mineral exploration. It is proving helpful in assessing the condition of crops, timberlands, water supplies, and many other resources. Some scientists liken the satellite's contribution to the invention of the microscope. This time, the whole earth is under a microscope. Sam M. Pickering Jr., Georgia's state geologist who has worked extensively with the satellite's data, says: "Before ERTS-1, we were crawling over an elephant's skin with a magnifying glass. Now we see the elephant."

In terms of potential economic payoff, ERTS may be the most important spacecraft ever launched. It is the first harbinger of those long-talked-about but elusive benefits of space research. More than 110 countries, including the Soviet Union and Communist China, have purchased ERTS pictures, and hundreds of scientists from corporations, universities, and government agencies have taken courses on how to use the data. Canada and Brazil have built their own multimillion-dollar receiving stations and get images from the satellite at little cost to them. Italy is building a station, Iran and Zaire are each planning one, and many other countries, including West Germany and Japan, are interested in the idea.

A magic mirror in orbit

In large measure, the satellite owes its success to the four remarkable "eyes" of its electro-optical imaging system. This is the "multispectral scanner," which consists of a mirror that oscillates inside a telescope and is connected by glass fibers to light detectors. (A more conventional video system had to be turned off early in the flight because of a circuit failure.) As the satellite passes over the earth, the mirror faces a continuous strip of land 115 miles wide. When light reflected by objects below hits the mirror, it is conducted by the glass fibers through four color filters to the photoelectric detectors. Each filter lets through only a narrow band of the light spectrum. The detectors thus see the image simultaneously in different wavelengths.

Scientists chose to record images in two visible and two infrared bands just beyond what the human eye can see. They selected these bands in order to make various classes of objects more visible. Vegetation, for instance, stands out especially well in infrared, while rocks are more visible in other spectral regions.

The system can even distinguish among different kinds of vegetation. Wheat, for example, reflects light differently than corn. Each class of objects on earth possesses its own distinctive fingerprint, or "spectral signature," determined by its atomic and molecular structure. The multispectral scanner picks up these signatures as electronic signals—voltage variations in its light detectors. The signals are then transformed into a digital format aboard the satellite and telemetered to earth, where they are recorded on magnetic tape.

Better than the best cameras

Technicians at NASA can then construct a photograph-like negative from the electronic signals in each spectral band. They may assign colors to the negatives and produce "false color" prints highlighting the different types of objects shown. In addition, the magnetic tapes can be manipulated by computers—without the need to print a picture first. For instance, using the different electronic signatures registered on tape, a computer program can print out the total acreage of, say, wheat, corn, or coniferous or deciduous trees. As many as thirteen different types of vegetation and soil have been classified by computers in a single area. General Electric, builder of ERTS-1, has a system that extracts data from computerized images in seconds and displays them on a TV-like screen and on paper with printers and plotters. As NASA Administrator James C. Fletcher puts it: "We see things from the ERTS perspective that we've never seen before with the best cameras or the sharpest eyes."

This novel approach to processing pictorial information electronically hints at one of the great powers of the system. When fully developed, ERTS could provide nothing less than a continuing, automated inventory of many of the world's resources. It has the sharpest eyesight of any civilian satellite launched so far. Enlargements of its images can show objects as small as 200 feet on a side, say, a big building or a pond slightly larger than an acre. To be sure, this is far below the capability of spy satellites, whose cameras can make out numbers on an automobile license plate. At this point, however, a resource-surveying satellite does not need a spy satellite's fine vision. Users would be hopelessly swamped with data they couldn't process.

The most obvious application of the satellite's pictures is in map making. Alden P. Colvocoresses, a cartographer with the U.S. Geological Survey, says that before ERTS was launched, many map makers were skeptical about the ability of an untested contraption—"a little mirror in space"—to produce images with the demanding fidelity and geometric precision required for map making. To the cartographers' delight, however, the scanner reproduced scenes on earth without the distortions present in aerial photographs taken from relatively low levels.

From 567 miles above the earth, the satellite can depict an area about the size of Maryland on a 1:1,000,000 scale (one inch equals about sixteen miles) in its true shape as if it were a plane. "The resulting image," says Colvocoresses, "is for practical purposes orthographic [i.e., an observer sees each point as if he were directly above it] and can be readily turned into a usable map."

Re-exploring Antarctica

ERTS images 115 miles on a side can easily be put together to form maps of whole countries and continents. A mosaic of the U.S. that would have required 100,000 aerial photographs was constructed with fewer than 600 images. Cartographers have found the images suitable for accurate mapping up to the 1:250,000 scale (one inch equals four miles)—a worldwide standard for medium-scale maps. For larger-scale maps, aerial photography still holds an advantage because of its finer resolution. But even large-scale maps of wilderness areas have been revised from data revealed by ERTS.

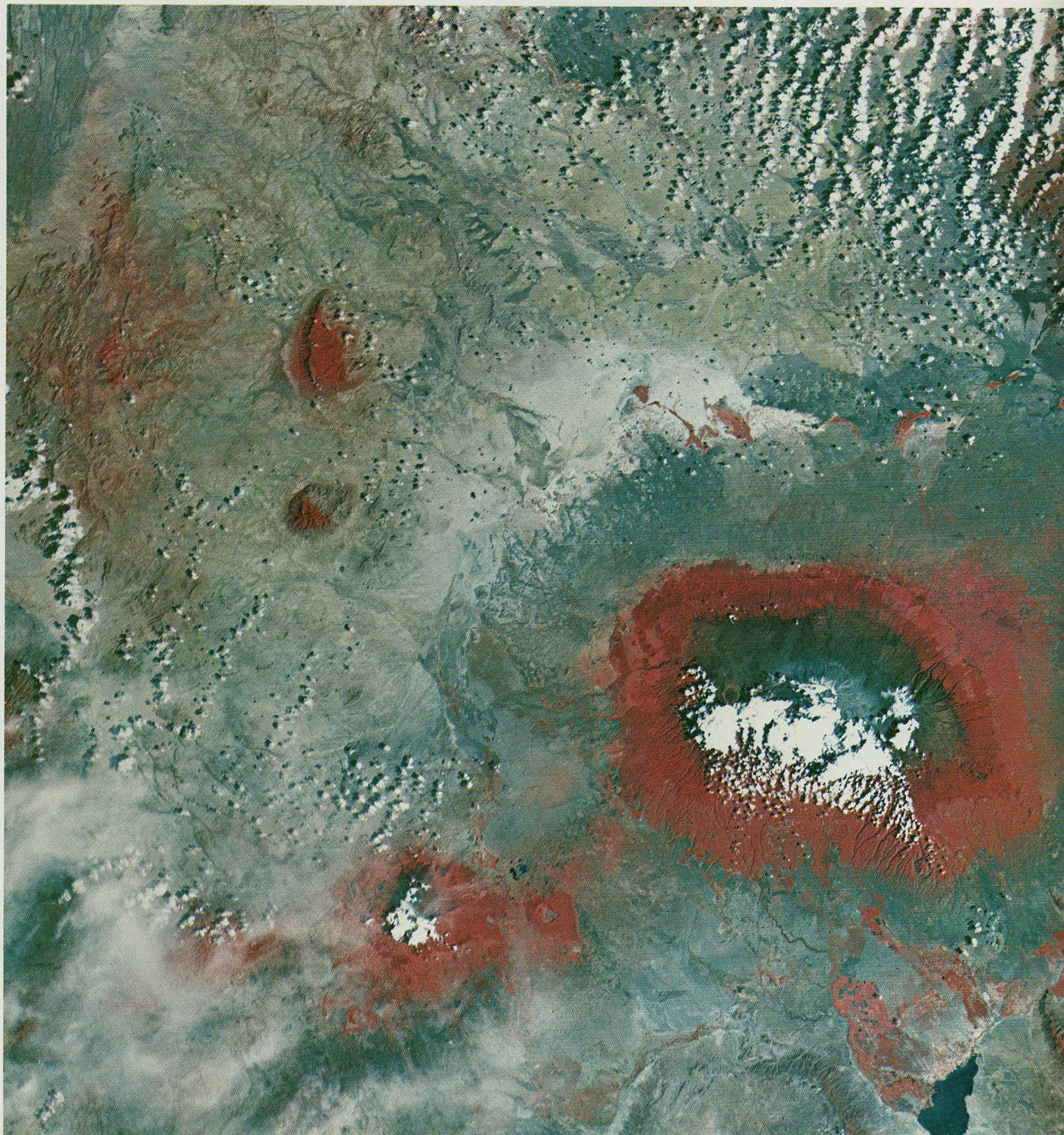
Using satellite imagery, the Bolivian government has prepared the most accurate map ever made of the country, including some previously uncharted lakes. Brazilians afflicted with land-speculating fever buy and sell hunks of their country's little-explored interior on the basis of satellite pictures. In Antarctica, where the U.S. has spent years and millions of dollars mapping the huge continent with aerial photography, ERTS has discovered whole mountain ranges and has indicated the need to redraw maps covering about 1,200 miles of the coast. Even in a state as well known as Massachusetts, the satellite has detected striking inaccuracies on conventional small-scale maps of the coastline.

As one map maker puts it, ERTS does away with "scissor cartography"—maps compiled from secondhand reports and clippings from older maps. The satellite also introduces the revolutionary concept of mapping the earth automatically, in days instead of the years consumed by conventional techniques. Even now, maps can be made from ERTS images rapidly and inexpensively. In Bangladesh, for example, one map maker took a slide made from an ERTS picture, projected it on a huge piece of paper hung on a wall, and in sixteen hours, with colored pencils, produced a land-use map of a portion of the country.

Beyond conventional cartography, the satellite makes possible an application of an exciting new concept of dynamic mapping—the construction of "living" maps of

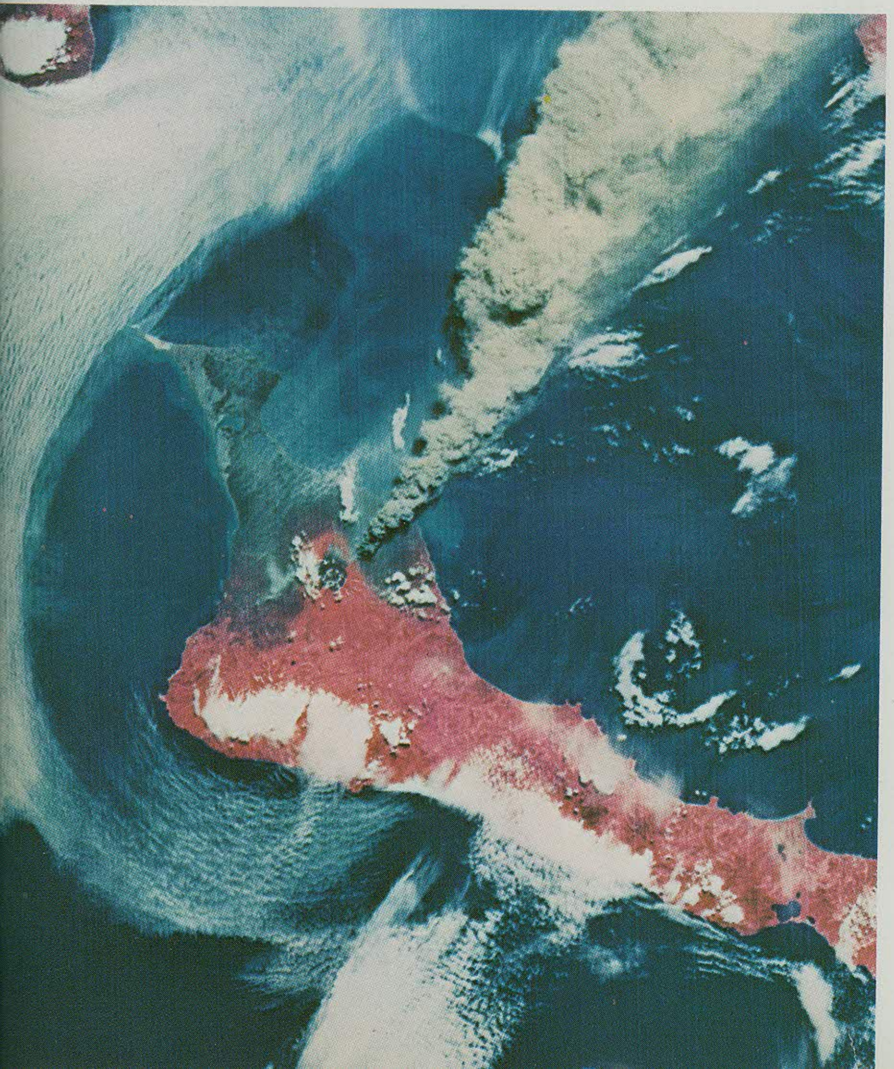
REVELATIONS FROM ON HIGH

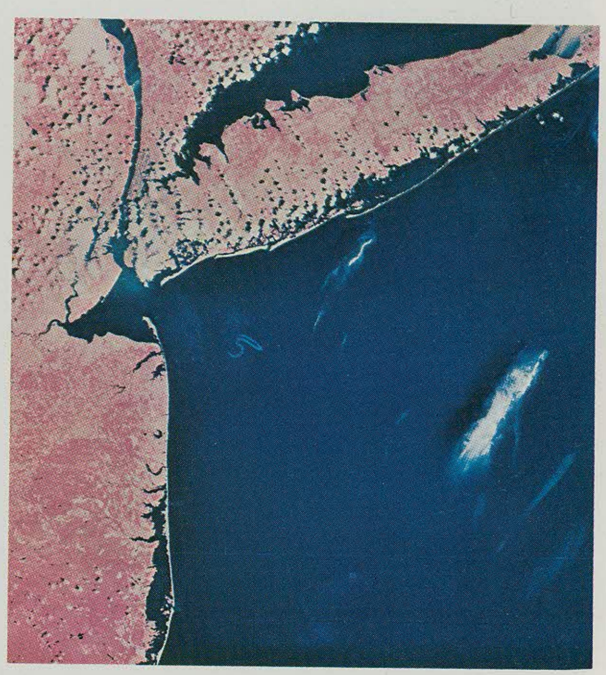
The peak of Africa's Mount Kilimanjaro, as pictured by ERTS, is partly covered by snow and clouds at the center of the red ring. The circle depicts forests as well as coffee and banana plantations, which are seen in the infrared spectrum by the satellite's detectors. The entire area shown is 115 miles on a side.



A great river in India, the Brahmaputra, carries huge loads of sediment from the mountains of Tibet and Burma. The dark-blue river channels interweave with the sand and silt deposits that stand out in lighter blue.

Blowing its top after lying dormant for 161 years, the volcano Tiatia on the Soviet Union's Kunashir Island erupted in 1973, sending a plume of ash-laden gases more than 15,000 feet in the air. Scientists think the semicircular arc of clouds may have been caused by the shock of the explosions, which occurred about once every minute.





Looking down on New York Harbor, the satellite sights acidic iron wastes illegally dumped by a barge. The waste shows up as the white squiggle, about five miles long, close to the harbor's mouth. It later hit New Jersey beaches.

A major problem for the Malagasy Republic is revealed by the light-colored effluent flowing into the Mozambique Channel. Because trees were cut down and the island was overgrazed, eroding soil is constantly carried off by the Mahajamba and Sofia rivers.

Shadows cast by the January sun accentuate the rugged topography of the Soviet Union's Primorsky region and adjacent China. In Peter the Great Bay near Vladivostok, the solid ice shows up light blue, while the darker tones signify ice that is drifting to sea. The reddish markings on the mountains are evergreens.

the world. As it passes over the same spot on earth every eighteen days, the spacecraft can track changing events —floods, surging glaciers, the movement of icebergs, melting snow cover, erupting volcanoes, and such man-made environmental effects as pollution. A private company in Canada retransmits ERTS pictures via facsimile to ships conducting seismic surveys in search of oil in the Arctic. The ship captains need to know whether there is clear water ahead to ensure that the ships run straight survey lines. The satellite's instant map permitted one Canadian ship navigating in a large ice floe to extend its survey seventy-five miles, saving more than $100,000 in operating costs.

The newfound ability to track change creates opportunities to control the environment and protect against disaster. On the scorching Red Sea coastal plain of Saudi Arabia, David Pedgley, a British scientist, has employed ERTS imagery to pinpoint areas where locusts may be breeding. Locusts need moist ground for their eggs to incubate; the moisture in turn nurtures vegetation that the insects use as food and shelter for the six weeks they take to mature. Pedgley has concluded that the satellite could become a powerful weapon in the battle against locusts by monitoring the growth of vegetation along the insects' invasion routes in Africa and Asia. Where images indicated a potential breeding area, ground checking could determine whether there were enough locusts to justify dropping insecticide from the air.

Though visual observation is its primary task, ERTS has also been set up as a radio-relay mast for data being collected by unmanned instrument stations on earth. Investigators have stashed away about 180 monitoring devices at such remote and dangerous places as the cones of volcanoes, storm-battered mountain peaks, and snake-infested Florida swamps. A set of instruments installed at Volcan de Fuego in Guatemala detected telltale mini-quakes and ground tilt, and radioed these data to ERTS for retransmission to scientists on the ground. The volcano erupted six days later—suggesting the feasibility of a satellite-assisted volcano patrol.

The mystery of the rings

The satellite's synoptic view of whole countries and continents has been revealing some startling and economically important news about geologic structures and their associated mineral deposits. The very first ERTS images clearly announced to geologists that a new chapter was about to open in their field.

In July, 1972, John M. DeNoyer, an Interior Department geophysicist who runs the Earth Resources Observation Systems (EROS) program, was watching the first images being processed in a darkroom at NASA's Goddard Space Flight Center in Maryland. The first picture, of the Ouachita Mountains in Oklahoma, was decorated with strange rings. "My God," exclaimed a NASA phototechnician, "our system has Newton's rings all over it!" He was referring to a defect in optical systems, first described by Sir Isaac Newton in 1675, that can be caused by improper positioning of the lenses. But after looking at the image himself, DeNoyer recognized the rings as geologic structures that often mark underground basins favorable to deposits of oil or other minerals. "They looked beautiful to me," he says.

Other ERTS images soon revealed the presence of many previously unseen faults and linear structures. Because of their size or their subtlety of expression, these features had gone unrecognized in conventional ground and aerial surveys. But on ERTS images—depicting the whole elephant—faults could be detected stretching for hundreds and even thousands of miles.

Glimpses of the prehistoric past

The satellite's view is providing insights into the way the earth was formed and its prehistoric past. In the U.S., South Africa, and elsewhere, ERTS has distinguished the vast outlines of ancient impact craters, suggesting that the earth underwent severe bombardment by meteorites just as did the moon and the nearby planets—Mars, Mercury, and Venus. The faults sighted by ERTS represent areas of weakness in the earth's crust. They apparently reflect fractures in the ancient "basement," the geologist's term for the layer of bedrock underlying sedimentary rocks, or they may be traces of the relatively more recent "drifting" of the continents.

Knowledge of the faults' locations can warn engineers where it would be unsafe to build bridges, tunnels, aqueducts, dams, and other large structures that could be endangered by weakened, smashed, or moving rocks within the faults. In Indiana, state geologists and the Earth Satellite Corp., a consulting firm, have shown that mine-roof collapses—the No. 1 killer of coal miners—occur most frequently along closely spaced or intersecting fractures that can be traced on ERTS images.

These corridors of weakness also mark a much happier geological phenomenon, the points where minerals in gaseous or liquid solution were forced upward from the interior of the earth. The minerals were often deposited along the faults and particularly at their intersections. Eventually, geologists are now convinced, the data will yield new insights into the history of mineral deposition. As it is, many geologists are already busily revising their ideas about where ore and oil are likely to be found.

Alaska provides a spectacular case in point. Shortly after the ERTS images started coming in, DeNoyer and William A. Fischer, senior scientist in the EROS program, were looking at a satellite picture of a naval petroleum reserve near Prudhoe Bay. Seeing something interesting in the image, Fischer telephoned Ernest H. Lathram in the U.S. Geological Survey office at Menlo Park, California, who, like Fischer, had firsthand experience searching for oil in the area for many years. Fischer asked Lathram to look at the same image. "Within a few minutes," says Fischer, "we were all seeing the same thing— the very strange pattern of alignment of the many small lakes. It almost had to be controlled by a deep-seated structure."

Because the area is so large, the alignment of the lakes was not readily apparent from either ground or aerial surveys. But as Lathram later delved into the sketchy seismic and magnetic studies of the lake area, he could see that the data seemed to support the conclusion that an elliptical structure underlies the lakes. This type of structure often signals the presence of gas or oil. Seismic profiles showed dips and arches in shallow strata where gas is often trapped. Deeper still, there may be oil. A medium-sized oil field had earlier been discovered at nearby Umiat, but no one had suspected that the lake region was a possible oil field.

Bigger than East Texas

Furthermore, ERTS information has allowed the Geological Survey to extend its maps of structures offshore from North Slope oil fields, indicating another promising area for exploration—albeit one made extremely difficult by dangerous ice floes. The scientists are excited by the fact that both the lake area and the offshore structures are large compared to oil fields in the continental U.S. The lake region alone is about fifty miles by thirty miles, bigger than the famous East Texas field that once supplied a quarter of the nation's oil.

A large number of oil companies—among them Continental Oil, Phillips Petroleum, and Superior Oil—are using ERTS imagery to better understand the areas they are exploring. John B. Miller, a geologist with Chevron Overseas Petroleum, Inc., reports that ERTS pictures saved his company time and money and supplied new exploration ideas in Kenya. Donald F. Saunders, a scientist with Geophoto Services, owned by Texas Instruments, has developed maps that relate geologic structures to potential oil and ore deposits, and he sells them—briskly, he says—for $1,500 a set. So far, no company has reported an oil strike that could be specifically attributed to information supplied by the satellite, but some geologists think finds will start coming in within months.

In searching for other minerals, prospecting from space has already produced actual discoveries. After seeing a promising new linear feature not far from La Paz, Bolivia, a geologist went into the area and returned with a rock laced with copper ore, found directly over the fault. In the U.S. Southwest, ERTS images revealed a large number of circular structures believed to be remnants of old volcanoes, some of them containing copper ore. And near Eli, Nevada, optimistic companies have staked claims on government land where ERTS images have revealed still another area with geology favorable to copper. As of now, nobody knows whether these locations will be economic to mine.

Besides looking for large structures, geologists scrutinize ERTS images for other distinctive clues to minerals near the surface. For example, images of some small Alaskan lakes appeared to be paler than others, indicating that these lakes hadn't frozen over. Fischer thinks that natural gas is seeping into the water.

Shallow ore deposits sometimes stunt the growth of vegetation in a way that can be detected by the satellite. ERTS images of vegetation on islands off Indonesia gave U.S. Steel geologists ideas about where to look for chromium. On the other hand, vigorous vegetation along certain geologic structures has supplied new insights into the location of underground sources of water. "The importance of dynamic changes to geology was generally not recognized until ERTS flew," says DeNoyer. "Now it has become obvious."

Using a computer technique called "band ratioing," technicians can process ERTS images to bring out geologic details invisible to the eye. The computer programs manipulate the millions of picture elements contained in each image, enhancing the desired signals in one spectral band and suppressing those in another in accordance with a desired ratio. Alexander F.H. Goetz, a geologist, and his associates at NASA's Jet Propulsion Laboratory in Pasadena, California, used the technique to find previously unknown aquifers near the Grand Canyon in Arizona, then went to the scene and successfully drilled for water. That was good news to ranchers in the area, some of whom have to have their water trucked in from fifty miles away.

"Companies are interested in this game"

Goetz and Lawrence Rowan of the Geological Survey also used band ratioing to bring out stark differences in rock types otherwise invisible on standard images. They tested the technique on an image of the famous Goldfield mining district of central Nevada. A green color on the image indicated that highly hydrated iron oxides and clays often associated with deposits of silver, gold, and copper were lying on the surface. After detecting twenty other spots in Nevada marked by that color, Goetz says, they checked those locations on the ground and found that "every single place turned out to have the hydrated iron oxides." Only about half those areas had been previously explored.

In collaboration with Continental Oil, Goetz is now investigating the possibility of locating copper deposits by the band-ratioing technique. "Companies are very interested in this game," he says. At the Goddard Space Flight Center, scientists are investigating band ratioing as a possible means of finding oil deposits. Mysterious hazy spots show up on ERTS images of oil fields in Oklahoma and Texas. The scientists want to determine if such anomalies can be associated with other known oil fields and, if so, whether they will be helpful in prospecting.

Other experiments with ERTS indicate that the satellite could make an important contribution to a worldwide survey of food production. To forecast the size of harvests with complete accuracy, good information is needed about the acreage planted in various crops. Faulty acreage estimates account for a quarter of the total error in crop forecasts, which can be off by more than 10 percent in the U.S. and far more than that in other parts of the world. Improving accuracy would lead to more efficient planning in all aspects of commodity processing and distribution, and tend to force down prices.

A study for NASA by Econ Inc. of Princeton, New Jersey, estimates that a 25 percent improvement in U.S. production forecasts for wheat alone would yield benefits to consumers as high as $212 million a year. And if a *worldwide* crop-monitoring system had been in effect, the U.S. might have known the extent of the shortfall in Soviet wheat production much earlier, and the Russians might not have been able to pull off the notorious grain deal that cost American consumers so dearly.

In experiments with ERTS images, scientists have achieved accuracy of 97 percent in identifying different crops. In a typical case, in which an ERTS picture of California's Central Valley was used, researchers delineated thirteen different agricultural classes by electronic signatures in about thirty minutes. This information was more detailed and up to date than that used by the Statistical Reporting Service of the Agriculture Department.

The emerging ability to make continuous inventory of the world's crops enabled Henry Kissinger to tell the food conference in Rome last year that systematic satellite surveys would soon become possible. In the past, the Soviet Union and other countries have objected, saying such surveys would somehow allow multinational corporations to cash in on advance knowledge of crop status. It's not clear how or if such fears can be stilled, but NASA and other agencies are going ahead with tests to see if ERTS data, in conjunction with weather reports and ground measurements, can result in a vastly improved forecasting system.

The bureaucrats try to shoot it down

For all its experimental success and future promise, ERTS is running into some difficulties more serious than the fear of economic espionage. For one thing, it is caught in a bureaucratic morass, with responsibility divided between NASA, which operates the spacecraft, and the Interior Department, which distributes the satellite data and tries to apply them in its own work. Other federal agencies that would use ERTS information, such as the Agriculture and Commerce departments, also want to have a say in operations. Moreover, though the program has cost more than $200 million so far, the White House Office of Management and Budget has cut back on relatively minor expenditures that could greatly speed up the distribution of data and increase the benefits to users.

The shortage of funds has created horrendous bottlenecks, forcing NASA to operate as if it were a Soviet department store, where customers stand in interminable lines to get their purchases. ERTS signals are received by three ground stations in the U.S.: at Fairbanks, Alaska; Goldstone, California; and Goddard, Maryland. But only Goddard is equipped to turn the electronic signals into pictures. The other stations mail their computer tapes to Goddard, and processing can take as long as six weeks. Goddard then sends the pictures to the Interior Department's data center in Sioux Falls, South Dakota, for distribution. Two months may pass before a user receives an ERTS image from Sioux Falls, four months before he can get a computer tape. Users for whom timeliness is important—such as managers of rangelands, watersheds, and timberlands—have been unable to employ ERTS data for any but experimental purposes because they can't get the pictures fast enough.

Designed to last only one year, ERTS-1 is already well into its third. With some components failing, it is finally nearing the end of its useful life. Last month, ERTS-2, an exact copy of its predecessor, was to be placed into orbit. A few years from now, NASA would like to launch a third resources satellite, which would offer improved resolution and accurate measurement of soil moisture, important data for crop forecasts and other uses. But the Office of Management and Budget has been arguing that the idea of the third spacecraft should be dropped. In the face of volumes of contrary evidence, OMB officials claim that the satellite's sensors are not advanced enough to justify extending ERTS beyond the experimental stage to make it a fully operational system.

It may pay for the trips to the moon

Considering that many users require more efficient distribution and an assurance of continuity before they will employ ERTS data in their operations, the response to the satellite thus far has been nothing short of phenomenal. About $2 million worth of satellite images were sold to commercial users last year. (Nine-by-nine-inch black-and-white prints covering an area 115 miles on a side cost $2; color prints and magnetic tapes cost more.) Exploration, timber, and agricultural companies account for a large part of the orders, but users range from wildcatters running one-man operations to geologists at Exxon, from schoolteachers to ecology experts at Disney World. About 25,000 visitors have flocked to the satellite data distribution center, even though it is located in remote Sioux Falls. And abroad, ERTS-1 has been producing incalculable goodwill for the U.S.

"The earth-resources program," says NASA Administrator Fletcher, "is going to pay for itself many, many times over, in terms of benefits to people not just in this country but also throughout the world. Very possibly, it may pay for the entire space program." To be sure, Fletcher might be expected to be enthusiastic—even hyperbolic—about his own agency's accomplishments. But to cripple or kill this program, after the millions of words spewed out about the coming "fallout" from space research, would certainly be foolhardy. END